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Fort Collins,
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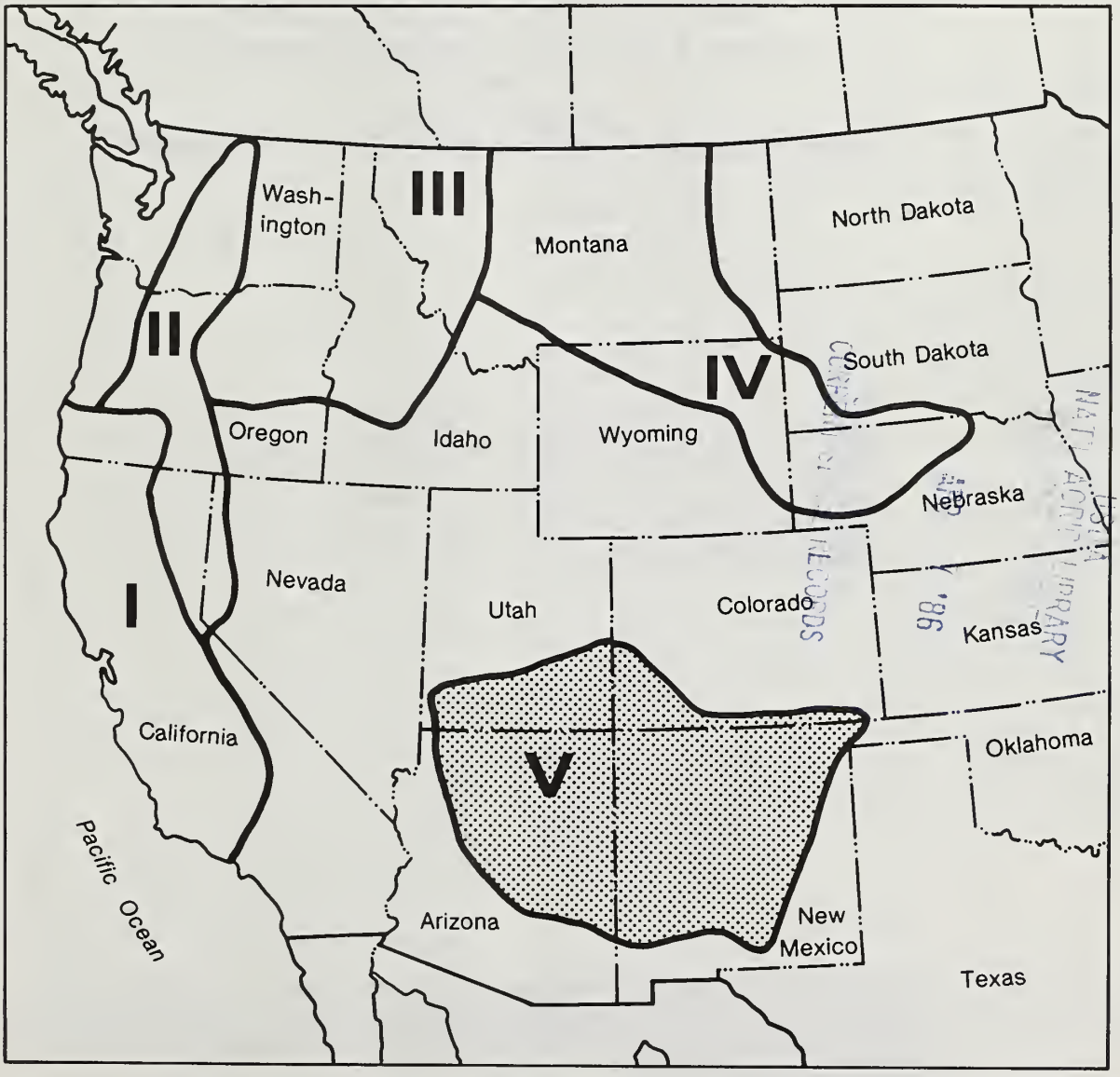
**Research Paper
RM-262**

Growth of Ponderosa Pine Thinned to Different Stocking Levels in Northern Arizona

Frank Ronco, Jr., Carleton B. Edminster, and David P. Trujillo



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USDA Forest Service
Research Paper RM-262

October 1985

Growth of Ponderosa Pine Thinned to Different Stocking Levels in Northern Arizona

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Abstract

A dense, immature ponderosa pine stand was thinned in 1962, 1972, and 1982 to six growing stock levels (30, 60, 80, 100, 120, and 150). Except for height, average tree growth characteristics (diameter, crown length, and width) were negatively correlated with residual stand density. Stand basal area and volume increment were positively related to stand density.

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Management Implications

This study demonstrates that the ability of Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) to respond to stand treatment provides considerable flexibility for the manager to choose initial stand management strategies. Furthermore, it still permits future changes as management objectives or market conditions change.

Early predictions (Schubert 1971) and the 20-year results presented here differ considerably, indicating that volume production estimates covering long periods of time should be interpreted with care. Management guidelines involving intermediate entries, however, can be formulated with a greater degree of certainty. For example, the study results suggest that a reasonable cutting cycle would be about 20 years, provided that there is a roundwood market when the second thinning is made. For sawtimber yields, in contrast, the minimum elapsed time between the first and second thinning appears to be about 30 years, with longer cutting cycles necessary if a minimum diameter limit of greater than 7 inches (17.8 cm) is desired.

To illustrate the application of such information under conditions where a roundwood market exists, it is assumed that (1) initial stand diameters are 2 to 2.5 inches (5.1 to 6.4 cm), and (2) a 20-year cutting cycle is imposed. All growing stock levels (GSLs) up to 120 then should yield a commercial second thinning of more than 2 cords per acre (12.60 m^3/ha). But, maintaining stands at the higher GSLs requires removing more smaller trees. Therefore, the selection of a management goal between GSLs 80 and 100 appears to provide a reasonable compromise between volume production and the number of trees to be removed.

In the absence of a roundwood market, management options are limited. Initial thinning of stands to GSLs between 60 and 80, under a 30-year cutting cycle, should result in a second thinning that will yield at least 1,000 fbm per acre (14.0 m^3/ha) of commercial sawtimber in trees 7 inches (17.8 cm) d.b.h. and larger. These GSLs are somewhat higher than those estimated by Alexander and Edminster (1980) for a 10-inch (25.4-cm) minimum sawtimber limit, demonstrating that initial GSLs must be reduced to 40, or cutting cycles must be lengthened, if the minimum sawtimber diameter is raised above 7 inches d.b.h. (17.8 cm). Once trees reach merchantable size, the manager can increase GSLs with each successive entry in an effort to approach volume production which might have been realized at a higher constant GSL of 120 (Alexander and Edminster 1980).

If only one precomercial thinning is feasible in ponderosa pine stands with small average diameters, management policies directed towards producing merchantable volumes in a reasonable period of time would be difficult to implement at high GSLs (Alexander and Edminster 1980). This conclusion tends to be supported by the low merchantable yields produced from the higher GSL plots in this study during the second entry; but, the results may be somewhat misleading because of the relatively short 10-year cutting cycle.

Although GSL 150 produced the greatest volume at this stage in the study, the risk of future beetle infestations, as stand density increases, discourages maintenance of such high stand densities over large areas. But, high GSLs may be necessary for initial thinning of dense sapling stands to strengthen residual trees against possible snow damage (Schubert 1974). Generally, however, lower GSLs should be implemented.

Tree heights generally averaged higher in stands thinned to lower GSLs; but it was not possible to detect significant differences with respect to residual basal areas. Thinning from below, especially with frequent entries such as the 10-year cutting cycle in this study, would tend to leave fewer, but taller trees, resulting in increased average heights at each entry (Alexander and Edminster 1980).

Relating growth parameters, such as periodic annual diameter increment, to growing stock levels was not attempted in this study for reasons that are discussed later. Instead, they were compared by regression analysis as a function of stand density. Nevertheless, GSLs are still a useful index for discussing general thinning responses and residual stand density in immature stands.

Because of the opposing growth behavior of individual trees and stands, yield objectives must be balanced when formulating management strategies. Of primary interest is the relationship between diameter growth and volume production—the former decreasing and the latter increasing with increasing stand density. The advantages associated with stands having lower growing stock levels and subsequent faster diameter growth, followed by earlier attainment of merchantable sizes, must be weighed against the lower overall productivity during the rotation of such stands. Such an analysis is especially important when the manager is limited in the number of precommercial thinnings that may be performed.

Introduction

A summary of early thinning studies of Rocky Mountain ponderosa pine by Gaines and Kotok (1954) showed that diameter growth in all study locations was greater in lightly stocked than in denser stands. In con-

trast, they reported that little or no increase in volume or basal area growth could be expected as a result of thinning. However, these studies did not test the low-reserve densities that may be desired in the future; nearly two-thirds of the plots were stocked with reserve densities exceeding 100 square feet of basal area per acre (22.96 m^3/ha). For these as well as other reasons, including incomplete data and single thinnings followed by long remeasurement periods, many previous thinning studies did not provide adequate information for management planning (Myers 1967).

Therefore, a study was begun throughout the West, in the early 1960s (Myers 1967) to obtain growth information over a range of stand and site conditions, with minimal operational or economic restrictions. Five study areas or provinces were defined, covering the uplift of the Black Hills in South Dakota, the Colorado Plateau of Arizona, and the mountains of California and Oregon. This paper reports results from the Arizona study area.

Study Area

Taylor Woods, a subdivision of the Fort Valley Experimental Forest, is approximately 9 miles (14.5 km) northwest of Flagstaff, Ariz., at an elevation of 7,435 feet (2,266 m). It is on the Colorado Plateau at latitude 35° 17′ N and longitude 111° 43′ W. All plots are within a 90-acre (36.4-ha) area on a gentle (4%), southwest-facing slope, in the *Pinus ponderosa/Festuca arizonica* habitat type.

Before the study began in 1962, the stand at Taylor Woods consisted of an overstory of sawtimber up to 21 inches (53.3 cm) in diameter at breast height (d.b.h.) and an understory of saplings and small poles. The lower stratum was considered even-aged, originating primarily from seeds germinating in 1919 after the exceptional seed crop from the previous year (Pearson 1950). Except for a few small areas scattered throughout the stand, the sawtimber and sapling/pole components occurred as separate groups; approximately 10% of the area was nonstocked.

Before the overstory was removed in 1962, two previous entries were made in the stand. In 1925, the tract was cut by the group selection method (Pearson 1950), accounting in part for some of the nonstocked openings. The second entry in 1942 was a partial cutting that reduced stocking within sawtimber groups by removing trees of poor form, high risk, and low vigor. The residual stand volume after the 1942 cut was about 1,800 board feet (fbm) per acre (25.2 m^3/ha), increasing to about 2,800 fbm per acre (39.2 m^3/ha) during the 20-year period from 1942 to 1962. During the summer and fall of 1962, all sawtimber was harvested in a final removal cut, leaving a dense, even-aged stand consisting of mostly 43-year-old small diameter saplings and poles (fig. 1). More than 80% of the trees were smaller than 3 inches d.b.h. (7.6 cm) (table 1); only 6% had reached a merchantable pulpwood size of 6 inches (15.2 cm).

Figure 1.—Typical unthinned stand at the Taylor Woods growing stock level study located on the Fort Valley Experimental Forest near Flagstaff, Arizona.

Site index for Taylor Woods was reported previously as 88 (Schubert 1971). Recently, however, it was recalculated to be 73, using site index curves (base age 100 years at breast height) developed by Minor (1964). The new determination—based on a total of 54 trees, 3 from each plot in this study—compares with an average site index of 55 for Arizona and New Mexico (Schubert 1971).

Average annual temperature, measured at Fort Valley Experimental Forest Headquarters (about 1 mile (1.6 km) from the study site), is 43° F (6.1° C); average daily temperatures range from 25° F (−3.9° C) in January to 63° F (17.2° C) in July (NOAA 1981). Mean maximum temperatures in January and July are 42° F (5.6° C) and 81° F (27.2° C), respectively (Sellers and Hill 1974). Annual precipitation averages 22 inches (55.9 cm), of which approximately 29% falls in July and August, the wettest months of the year. The summer rainy season is bracketed by spring and fall droughts; the latter are less severe and of shorter duration. Total yearly snowfall averages 97 inches (246 cm) (Sellers and Hill 1974).

The soil at Taylor Woods is classified as a Typic Argiboroll, cool, fine montmorillonitic (USDA 1975).[3] It is deep and well drained, developing from a mixed alluvium derived from volcanic material, primarily basalt. The A horizon is rather shallow, extending to only 4 inches (10 cm); but the remainder of the soil profile reaches a depth of from 45 to more than 60 inches (114 to more than 152 cm) before bedrock of fractured basalt is encountered.

Methods

Six growing stock levels (GSL) are being tested at Taylor Woods: 30, 60, 80, 100, 120, and 150 (fig. 2). These growing stock levels are a numerical index designating the square feet of basal area that residual

[3] *Personal communication with George T. Robertson, Soil Scientist, Supervisor's Office, Coconino National Forest, Flagstaff, Arizona, January 28, 1983.*

Table 1.—Stand characteristics before thinning a 43-year-old ponderosa pine forest to six growing stock levels (GSL).[1]

GSL goal	Plot no.	Plot size	Total trees/acre	Basal area/acre	Average d.b.h.
		acre		*ft²*	*inches*
30	7	1.24	8,930	226	2.2
	16	0.75	3,750	176	2.9
	18	1.00	3,910	184	2.9
60	3	0.80	5,310	190	2.6
	15	0.75	3,140	194	3.4
	17	0.75	2,450	166	3.5
80	6	0.82	9,940	190	1.9
	11	0.75	4,730	205	2.8
	14	0.75	5,000	223	2.9
100	1	0.80	6,200	206	2.5
	9	0.75	7,050	198	2.3
	13	0.75	7,810	247	2.4
120	2	0.80	7,440	182	2.1
	5	0.80	5,960	212	2.6
	12	0.75	3,620	223	3.4
150	4	1.00	6,120	211	2.5
	8	1.00	6,460	251	2.7
	10	0.75	7,380	272	2.6
Average			5,844	209	2.7

[1]*The data for stand characteristics were obtained from two 0.05-acre sample areas per plot, measured after the 1961 growing season.*

stands have, or will have, when the average diameter at breast height of the residual stand is 10 inches (25.4 cm) or more.[4] Stands with trees smaller than 10 inches (25.4 cm), when thinned, contain residual basal areas that are less than the designated GSL. Such basal areas vary within a given GSL, depending on average stand diameter after thinning (fig. 3). Each GSL was replicated three times, with plots ranging in size from 0.75 to 1.24 acres (0.30 to 0.50 ha) (table 1).

The original study plan specified 2-acre (0.81-ha) plots, each with a corresponding buffer zone, spaced irregularly throughout the stand in order to obtain uniform, well-stocked areas of even-aged trees. However, stand heterogeneity caused by unstocked areas and groups of sawtimber precluded such a study design. Instead, it was necessary to locate plots using stand uniformity as the selection criterion, resulting in some common plot boundaries and the subsequent lack of a buffer zone. To lessen such edge effects, similar treatments were assigned to plots with a common boundary. Otherwise, a 1-chain (20.1-m) wide buffer zone was established with densities corresponding to those of respective plots.

A prethinning inventory was made at the end of the 1961 growing season for each plot, expressing the data on a per acre basis, where appropriate (table 1). The number of trees ranged from 2,450 to 9,940 per acre (6,054 to 24,561/ha); basal areas varied between 166 and 272 square feet per acre (38.1 and 62.4 m^2/ha). Average diameter of trees varied from 1.9 inches (4.8 cm) in plot 6 to 3.5 inches (8.9 cm) in plot 17.

[4]*Average stand diameter at breast height is the diameter of the tree of average basal area.*

Plots were marked according to specified density goals and thinned in the fall of 1962 for the first time. Plots were remarked, again to the prescribed GSL, after the 1972 and 1982 growing seasons and were thinned before the subsequent growth period began. Because only a very small portion of the trees thinned in 1962 were pulpwood size, all material was lopped and scattered. In contrast, trees cut in 1972 and 1982 were utilized to a 4-inch (10.2-cm) top diameter inside bark and were sold as pulpwood, together with thinnings from the stand outside the immediate study area. In 1972, slash was lopped and scattered; whereas, because of the fire hazard posed by the 1982 thinning, it was hand-carried from the plots, piled, and burned.

During the initial marking of the stand in 1962, trees to be thinned were selected on the basis of diameter, spacing, crown position, and tree condition. All trees with dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Hawksworth and Wiens) were cut, as were those with poor form, excessive limbiness, porcupine damage, and poor vigor. In general, the best dominant and codominant trees from 3 to 8 inches (7.6 to 20.3 cm) d.b.h. were left; trees outside this diameter range were retained only when good quality trees of preferred size were not available. Except for diameter restrictions, similar criteria were applied in subsequent thinnings.

All residual trees were identified by a numbered metal tag; and at each 5-year measurement period, the following data were recorded: (1) diameter (breast height) to the nearest 0.1 inch (0.25 cm), (2) crown position class, (3) crown quality class, and (4) tree condition. Crown quality considered branching symmetry

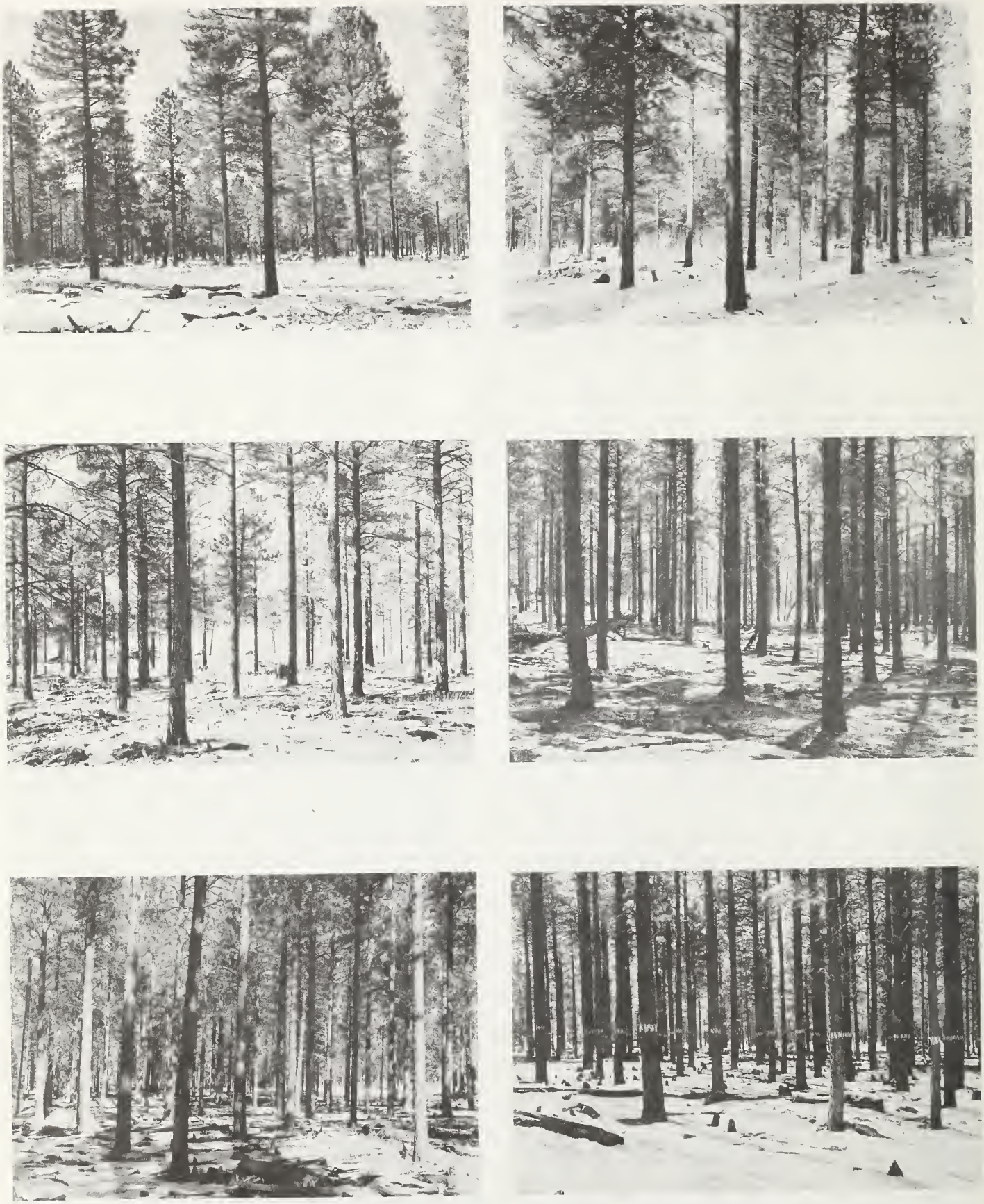

Figure 2.—Typical 1982 appearance of ponderosa pine plots at Taylor Woods thinned in 1962, 1972, and 1982 to different growing stock levels (GSLs).

and whether crown length exceeded one-third or more of total tree height; whereas tree condition, in addition to showing causes of mortality, also identified common defects and provided some measure of their intensity or effect.

Total height and live crown length and width of trees were subsampled on each plot at each 5-year measurement. Ten residual trees, if available, in each 1-inch (2.5-cm) diameter class, were randomly selected on each plot in 1962. Measurements were made to the nearest foot. At subsequent measurement periods, the same trees were measured on each plot. To estimate heights for trees not measured, the following model was fitted using stepwise regression, with deletion of nonsignificant terms, for each plot at each measurement period (Curtis 1967):

$$\log (H-4.5) = b_0 + b_1 \log D + b_2 (\log D)^2$$

where: log = common (base 10) logarithm
H = tree total height (feet)
D = tree d.b.h. (inches)
b_0, b_1, b_2 = regression coefficients.

Volume computations for each plot were based on all trees. Tree stem volumes were computed using gross volume equations for unforked blackjack pines on the Coconino, Lincoln, and Tonto National Forests (Hann and Bare 1978). Total cubic volume was computed for all trees. Merchantable cubic volume was computed for all trees 5 inches (12.7 cm) d.b.h. and larger to a 4-inch (10.2-cm) top diameter inside bark. Scribner board foot volume was computed for all trees 7 inches (17.8 cm) d.b.h. and larger to a 6-inch (15.2-cm) top diameter inside bark.

Statistical comparisons based on analysis of variance by GSL treatments were considered to be inappropriate, because of variation in residual basal areas—described in detail under Results and Discussion—that resulted from normal differences in tree diameters and thinning discrepancies. Instead, regression analysis of periodic annual increments of average tree and stand characteristics as a function of stand density (expressed by residual basal areas after the 1962 and 1972 thinnings) was used to model trends by density level and to demonstrate differences between the first (1963–72) and second (1973–82) growth periods. Ten-year growth periods were used to minimize variability resulting from climatic fluctuations during the rather short, 5-year remeasurement periods. For each characteristic, separate equations were computed for each time period using various functional forms of residual basal area; the form which resulted in the best fit is presented here. Coefficients of the two equations then were tested for equality using the test for identical linear models (Graybill 1976). If the significance level of the resulting test statistic was less than 0.05, the two equations were assumed to be different; if the significance level was greater than 0.10, the equations were assumed to be identical, and a single equation was computed by merging observations from the two growth periods. If the significance level fell between 0.05 and 0.10, all three equations were graphed. If the merged-data equation adequately fitted the range of data, then only the single equation was presented.

If the equations for the two growth periods were significantly different, the slope coefficients of the equations were tested for equality using a t-test. This test was used to determine if the growth relationships to stand density were similar for both periods, with differences between the equations caused by different intercept terms.

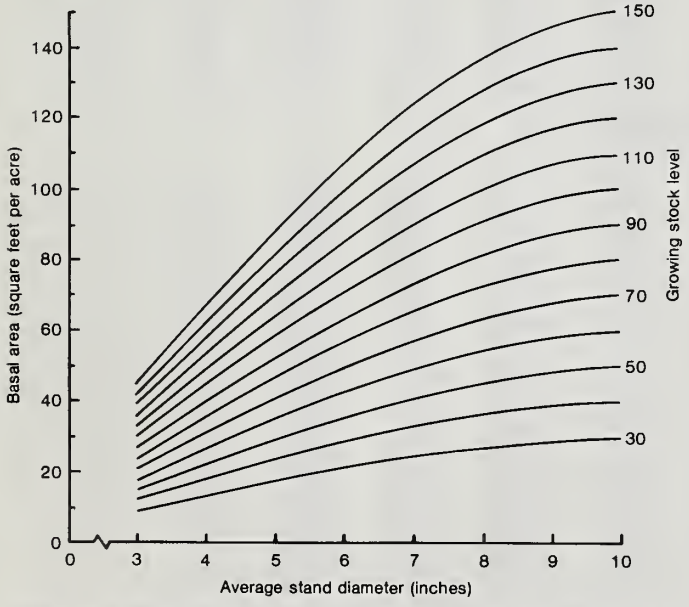

Figure 3.—Basal area after thinning in relation to average pre-thinned stand diameter for varous growing stock levels tested at Taylor Woods.

Results and Discussion

Stand characteristics over the 20-year period are shown in table 2. In contrast to the work by Oliver (1979) and Barrett (1983), growth results in this study can be compared with GSL only in a general way. Statistical correlations with GSLs would not be valid, primarily because variation in tree size in the natural stand at Taylor Woods varied considerably more than that which would be expected in the plantation thinned by Oliver and presumably the pole stand thinned by Barrett. Because of this variation in diameter, residual basal areas of plots in any given GSL were not uniform (within any given GSL, basal area varies with diameter (fig. 3)) especially at the higher GSLs. Variation was present between GSLs as well. For example, prescribed residual basal areas between plots after initial thinning ranged from 60 to 79 square feet per acre (13.8 to 18.1 m^2/ha) in GSL 120, and from 68 to 80 square feet per acre (15.6 to 18.4 m^2/ha) in GSL 150, demonstrating considerable overlap in basal areas between the two treatments.

Not only were differences in basal areas a result of natural variation in diameter, but marking practices during plot treatment also contributed. For example,

Table 2.—Stand characteristics of thinned plots at Taylor Woods at 5-year intervals, including those immediately after initial and two subsequent thinnings.

GSL goal	Plot No.	Trees/ acre	Aver. d.b.h.	Aver. height	Crown Dimensions			Volume/acre			Basal area/acre	Mortality/ acre
					Length	Width	Live crown	Total cubic feet	Merch. cubic feet	Merch. board feet		
			inches		*feet*		*percent*				*ft²*	*no.*
					After initial thinning (1962)							
30	7	132	5.1	24	12	8	51	188	96	23	19	-
	16	119	5.9	26	13	10	49	250	180	78	23	-
	18	131	5.4	26	12	9	47	217	129	44	21	-
60	3	272	5.0	22	11	8	50	353	192	60	38	-
	15	256	5.4	24	12	10	49	407	246	166	41	-
	17	219	5.8	25	12	9	47	445	306	193	40	-
80	6	352	5.0	24	12	8	52	458	236	92	48	-
	11	284	6.0	30	14	10	48	644	457	264	56	-
	14	340	5.3	26	12	8	46	544	315	83	52	-
100	1	374	5.4	24	13	8	53	584	377	269	59	-
	9	441	4.6	25	12	9	48	520	233	76	52	-
	13	460	5.0	27	12	9	44	688	347	156	62	-
120	2	468	5.4	24	12	8	52	740	467	306	74	-
	5	521	4.6	23	11	8	48	571	287	97	60	-
	12	429	5.8	28	13	9	46	912	625	404	79	-
150	4	667	4.6	22	10	7	48	734	352	140	78	-
	8	700	4.6	25	11	8	44	807	336	104	80	-
	10	699	4.2	26	12	8	44	694	260	67	68	-
					After first 5 years (1967)							
30	7	103	6.8	27	15	10	54	283	230	194	26	29
	16	109	7.5	31	17	12	55	417	353	470	34	10
	18	121	6.8	31	17	11	54	363	292	261	31	10
60	3	246	6.4	26	14	10	54	563	430	328	54	26
	15	248	6.5	28	16	11	55	634	484	504	57	8
	17	209	6.9	29	16	10	53	670	547	621	54	10
80	6	308	6.2	28	15	11	54	659	487	346	65	44
	11	256	7.1	34	18	12	52	907	752	869	71	28
	14	299	6.4	31	16	11	52	784	599	373	67	41
100	1	319	6.6	29	16	10	54	837	655	820	76	55
	9	383	5.7	29	15	11	51	737	483	298	67	58
	13	369	6.1	32	16	11	50	918	669	505	76	91
120	2	422	6.4	28	15	10	54	1,030	776	841	93	46
	5	445	5.6	27	14	10	52	787	526	333	76	76
	12	375	6.8	32	16	11	50	1,216	972	1,095	94	54
150	4	605	5.3	25	12	9	51	960	601	367	94	62
	8	623	5.4	30	13	9	47	1,097	644	340	98	77
	10	595	5.1	29	14	10	49	940	512	241	86	104
					After second 5 years (1972)							
30	7	103	8.5	31	18	12	59	497	438	867	41	0
	16	109	9.2	35	21	13	61	718	645	1,609	51	0
	18	121	8.6	36	21	13	58	648	573	1,160	49	0
60	3	244	7.5	29	17	12	58	856	726	1,094	75	2
	15	247	7.6	32	19	13	59	962	820	1,378	78	1
	17	209	8.2	33	19	12	59	1,047	918	1,783	76	0
80	6	307	7.1	32	18	13	57	980	811	961	85	1
	11	251	8.1	37	20	14	55	1,235	1,078	1,960	90	5
	14	296	7.5	33	18	12	54	1,172	997	1,343	92	3
100	1	305	7.5	32	19	12	58	1,136	957	1,730	94	14
	9	381	6.6	32	18	12	55	1,101	868	911	91	2
	13	369	7.0	35	19	12	54	1,305	1,063	1,302	99	0
120	2	420	7.1	31	18	11	56	1,422	1,173	1,766	117	2
	5	442	6.4	30	17	11	55	1,135	874	970	100	3
	12	373	7.6	35	18	12	52	1,646	1,399	2,351	118	2
150	4	605	6.1	27	15	9	54	1,352	989	986	121	0
	8	622	6.0	30	16	10	52	1,466	1,054	903	124	1
	10	592	5.9	32	17	11	53	1,350	940	715	112	3

Table 2.—Stand characteristics of thinned plots at Taylor Woods at 5-year intervals, including those immediately after initial and two subsequent thinnings.—Cont.

GSL goal	Plot No.	Trees/ acre	Aver. d.b.h.	Aver. height	Crown Dimensions			Volume/acre			Basal area/acre	Mortality/ acre
					Length	Width	Live crown	Total cubic feet	Merch. cubic feet	Merch. board feet		
					After second thinning (1972)							
30	7	63	9.3	36	22	13	61	383	343	799	30	-
	16	53	10.2	40	23	14	59	446	408	1,145	30	-
	18	68	9.1	37	22	14	59	416	373	831	31	-
60	3	141	8.5	34	20	13	59	677	597	1,093	55	-
	15	144	8.6	35	21	14	59	747	661	1,310	58	-
	17	133	9.0	38	23	14	59	844	757	1,664	59	-
80	6	220	7.7	34	19	14	57	844	725	948	70	-
	11	187	8.6	39	22	15	55	1,078	961	1,897	76	-
	14	207	8.1	36	20	13	54	971	849	1,283	74	-
100	1	264	7.9	33	19	12	58	1,103	955	1,730	90	-
	9	308	7.0	34	19	13	56	1,019	841	895	83	-
	13	283	7.5	37	21	13	55	1,164	994	1,280	86	-
120	2	324	7.7	34	19	12	56	1,320	1,136	1,766	106	-
	5	376	6.8	31	18	12	56	1,102	876	970	96	-
	12	311	8.0	39	20	14	52	1,541	1,347	2,289	109	-
150	4	503	6.5	29	16	10	54	1,304	989	986	116	-
	8	503	6.5	32	17	11	52	1,371	1,048	903	114	-
	10	541	6.0	33	17	12	53	1,299	914	690	107	-
					After third 5 years (1977)							
30	7	63	10.6	38	26	14	66	554	507	1,563	39	0
	16	53	11.6	43	27	16	62	624	578	2,014	39	0
	18	67	10.6	39	25	15	64	573	524	1,594	41	1
60	3	141	9.4	38	22	14	59	926	835	2,046	70	0
	15	143	9.6	37	23	15	61	983	888	2,296	72	1
	17	131	9.9	41	25	14	61	1,075	982	2,677	70	2
80	6	220	8.4	38	22	14	58	1,114	983	1,768	84	0
	11	184	9.3	41	23	14	56	1,292	1,168	2,839	88	3
	14	207	8.9	39	21	14	54	1,278	1,145	2,361	89	0
100	1	260	8.5	36	20	12	58	1,365	1,210	2,666	103	4
	9	308	7.7	37	21	11	56	1,347	1,164	1,735	100	0
	13	280	8.1	40	22	12	55	1,468	1,291	2,205	101	3
120	2	320	8.3	36	20	11	55	1,560	1,369	2,572	119	4
	5	376	7.4	34	20	11	57	1,395	1,179	1,698	112	0
	12	305	8.6	42	22	12	52	1,856	1,656	3,476	123	6
150	4	503	6.9	32	16	9	51	1,620	1,296	1,662	132	0
	8	502	7.0	35	18	10	50	1,719	1,410	1,572	132	1
	10	533	6.6	36	18	10	51	1,632	1,251	1,303	125	8
					After fourth 5 years (1982)							
30	7	63	12.1	41	28	16	67	742	686	2,540	50	0
	16	53	13.1	48	32	16	66	870	814	3,282	50	0
	18	65	11.9	42	28	16	66	767	711	2,570	50	2
60	3	141	10.5	41	25	14	61	1,246	1,142	3,498	86	0
	15	143	10.6	41	25	13	62	1,298	1,189	3,730	88	0
	17	131	10.9	44	28	15	64	1,382	1,278	4,105	84	0
80	6	220	9.1	40	25	13	61	1,450	1,305	2,968	100	0
	11	180	10.1	44	25	14	57	1,577	1,444	4,149	100	4
	14	204	9.8	42	24	14	57	1,611	1,466	3,786	106	3
100	1	260	9.2	38	23	12	60	1,718	1,545	3,975	121	0
	9	308	8.4	39	23	12	58	1,680	1,486	2,854	118	0
	13	279	8.8	43	25	12	57	1,879	1,685	3,536	117	1
120	2	320	8.9	37	21	11	57	1,946	1,736	3,889	138	0
	5	376	8.0	36	22	12	59	1,706	1,488	2,692	130	0
	12	299	9.2	45	24	12	53	2,230	2,021	4,993	138	6
150	4	503	7.5	34	18	10	54	1,981	1,660	2,666	153	0
	8	502	7.5	38	19	10	51	2,119	1,810	2,561	153	0
	10	533	7.1	38	20	10	53	2,162	1,760	2,349	147	0

Table 2.—Stand characteristics of thinned plots at Taylor Woods at 5-year intervals, including those immediately after initial and two subsequent thinnings.—Cont.

GSL goal	Plot No.	Trees/ acre	Aver. d.b.h.	Aver. height	Crown Dimensions			Volume/acre			Basal area/acre	Mortality/ acre
					Length	Width	Live crown	Total cubic feet	Merch. cubic feet	Merch. board feet		
					After third thinning (1982)							
30	7	36	12.5	43	30	17	70	451	418	1,606	30	-
	16	29	13.7	49	32	16	66	528	495	2,079	30	-
	18	37	12.2	45	30	16	67	473	439	1,631	30	-
60	3	94	10.8	41	25	14	63	892	820	2,617	60	-
	15	88	11.2	44	28	15	64	910	838	2,827	60	-
	17	89	11.0	46	29	15	64	993	920	3,031	60	-
80	6	163	9.4	41	25	14	61	1,158	1,048	2,556	79	-
	11	136	10.4	44	26	14	57	1,272	1,169	3,501	79	-
	14	148	10.0	42	24	15	58	1,237	1,130	3,069	81	-
100	1	196	9.7	40	24	13	61	1,439	1,303	3,607	100	-
	9	224	8.8	40	24	13	59	1,384	1,238	2,648	95	-
	13	216	9.1	44	26	13	58	1,560	1,408	3,179	97	-
120	2	255	9.2	38	22	11	58	1,659	1,490	3,542	117	-
	5	298	8.3	38	22	12	58	1,502	1,324	2,576	112	-
	12	241	9.5	45	25	13	55	1,944	1,770	4,584	118	-
150	4	400	7.8	35	19	10	54	1,750	1,498	2,613	133	-
	8	405	7.7	39	20	11	51	1,868	1,616	2,517	132	-
	10	421	7.6	40	21	11	54	1,944	1,657	2,330	131	-

residual basal areas per acre after the 1962 thinning were not as precise as would have been desired. Residuals ranged from an understocking in plot 1 to an overstocking in plot 13; both varying from the proper stocking by an identical amount, 4.2 square feet (0.39 m^2). Furthermore, all plots varied from the prescribed basal area to some degree; but eight, mostly in GSLs 100 and above, exceeded the allowable variation. In contrast, residual basal areas per acre after the 1982 thinning were within 0.5 square feet (0.05 m^2) of the prescribed amount. In 1972, residuals varied somewhat more, but were well within the allowable variation of 2 square feet (0.19 m^2) specified in the study plan.

Discrepancies were further aggravated by an unscheduled thinning in 1964 of trees damaged by snow in early spring of 1963. About 12% of the trees in the study were affected, essentially those that averaged 2 inches (5.1 cm) smaller in d.b.h. and 8 feet (2.4 m) shorter than the original stand. These damaged trees, as well as eight others that were killed by pine engraver beetles (*Ips pini* (Say)) the first year, were removed before the start of the third growing season.

Based on the assumption that diameter growth was linear between 1962 and 1967—plots were not remeasured in 1964—residual basal areas were calculated after dead and damaged trees were removed, before the beginning of the 1964 growing season. The resulting values indicated that basal areas per acre varied from the prescribed GSL by amounts ranging from −9.5 to +5.1 square feet (−2.2 to +1.2 m^2/ha). Furthermore, most of the discrepancies resulted in understocking, especially in GSLs 100 and higher. While part of the understocking could be attributed to additional cutting, some was associated with the resulting increased stand diameter, which, in turn, raised the residual basal area requirement to correspond with the new average stand diameter.

According to Schubert (1971), removal of damaged trees in 1962 probably had little effect on residual tree growth during the first 5-year period (1962–67), because examination of increment cores indicated that only trees in GSL 30 increased in ring width the first year after thinning. In contrast, trees in GSLs 120 and 150 did not respond until the third year. The effect of such removal on growth of the residual stand during the second 5-year period (1967–72) is not precisely known.

In figures 7 to 10, various growth parameters in relation to basal area are plotted separately for the 1963–72 and 1973–82 growth periods. Statistical tests showed that the equations for the curves were significantly different; but the relationship between the growth parameters and stand density were similar, indicating that the differences were caused by different intercept terms. Therefore, it was assumed that the values for periodic annual increment derived from the equations were decreasing with stand age, as reflected by reduced intercept values for the second period. This decrease is to be expected, because periodic annual increment culminates early in the life of a stand and decreases with increasing stand age to intersect the point of culmination of mean annual increment. The rate of decrease in periodic annual increment is expected to be greatest around the age of culmination of mean annual increment and should level off somewhat at higher stand ages (Davis 1966).

Diameter Growth

Periodic annual diameter (breast height) (fig. 4) growth ranged from 0.34 to 0.15 inch (0.86 to 0.38 cm), decreasing with increasing basal area during the first period, and from 0.30 to 0.10 inch (0.76 to 0.25 cm) during the second period (table 3). Diameter growth was strongly negatively correlated with residual basal area during both periods. Coefficients of determination (R^2) for equations predicting mean annual diameter growth as a function of the logarithm of residual basal area were 0.962 and 0.940 for the two periods, respectively. The significance level of 0.08 for the test of identical equations was not decisive. A plot of the first and second period equations with the merged equation showed the latter to be between the single period equations throughout most of the range of data; the only appreciable difference between the two single period equations was at higher basal areas than were present during the first period. The merged equation adequately fits the total range of data for both time periods:

$$DG = 0.76393 - 0.14016 \ln BA$$
$$R^2 = 0.976$$
$$S_{y \cdot x} = 0.010$$

where: DG = periodic annual d.b.h. growth (in).
BA = residual basal area per acre (ft^2).
ln = natural (base e) logarithm.

Average periodic annual diameter growth for all GSLs was less during the second 10-year growth period (table 3) because of increased residual basal areas after the second thinning. Barrett (1983) found the opposite trend of increasing growth with time; however, his plots in central Oregon were near the threshold average diameter of 10 inches (25.4 cm) where thinning results in a constant residual basal area.

Results from both central Oregon (Barrett 1983) and northern California (Oliver 1979) show relationships of periodic annual diameter growth to residual stand density similar to that shown in figure 4, but with shifts upward partly because of higher site qualities at those study areas. Previously published results from Taylor Woods (Schubert 1971) show the same trend, but with a small shift downward. This lesser growth rate is expected with the response delay which occurred during the first 5-year period after initial thinning. Barrett (1983) noted that growth rate generally decreased as residual basal areas increased from 30 to 100 square feet per acre (6.89 to 22.96 m^2/ha); there was little difference at the higher residual densities. Testing this observation at Taylor Woods will require at least two more growth periods when average diameters for the denser treatments are greater than 10 inches (25.4 cm).

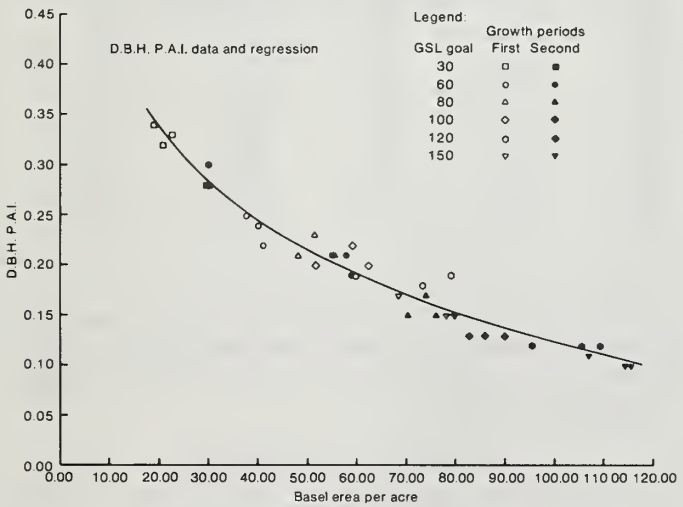

Figure 4.—Relationship of periodic annual breast height diameter (d.b.h.) growth to residual basal area for the combined periods (1963-82).

Height Growth

Periodic annual height growth of measured trees (fig. 5) ranged from 1.0 to 0.5 foot (0.30 to 0.15 m), decreasing with increasing basal area during the first period, and from 0.8 to 0.4 foot (0.24 to 0.12 m) during the second period (table 3). Height growth during the first period was negatively correlated with residual basal area, but was not significantly related to residual basal area during the second period. Only the first period equation shown below is plotted in figure 5:

$$HG = 1.48419 - 0.19910 \ln BA$$
$$R^2 = 0.627$$
$$S_{y \cdot x} = 0.071$$

where: HG = periodic annual height growth (ft).

During the first five years after initial thinning, Schubert (1971) found that annual height growth ranged from 0.7 to 0.5 foot (0.21 to 0.15 m), decreasing with increasing stand density. Similarly, the adjustment effects of thinning continued during the remainder of the first 10-year growth period. Oliver (1979) indicated that height growth was related to tree diameter after thinning, with the relationship holding across GSLs. While he noted a trend of decreased height growth with increasing GSL, neither he nor Barrett (1983) could demonstrate a significant relationship with GSL.

After an initial period of adjustment, a similar nonsignificant trend appears to be developing at Taylor Woods. This trend may become more apparent as plots at the higher GSLs reach greater residual densities. Although the average tree height of residual stands was greater at lower than at higher GSLs after 20 years (table 2), the differences were probably related to cultural practices that removed shorter trees of poor form during thinning, rather than increased growth rates associated with lower stand densities.

Crown Length Growth

Periodic annual crown length growth of measured trees (fig. 6) ranged from 0.9 to 0.3 foot (0.27 to 0.09 m), decreasing with increasing basal area during the first period, and from 0.8 to 0.2 foot (0.24 to 0.06 m) during

Table 3.—Periodic annual growth by 10-year periods between thinnings in even-aged ponderosa pine thinned to different growing stock levels (GSL) in 1962 and 1972.

GSL goal	Plot	Residual basal area	D.b.h.	Height	Crown length	Crown width	Basal area	Total volume	Merchantable volume
		ft²/acre	*inch*	*ft*			*ft²/acre*	*ft³/acre*	
				1963–1972 period					
30	7	19.1	0.34	0.8	0.6	0.4	2.2	31.0	34.2
	16	22.8	0.33	1.0	0.9	0.4	2.8	46.9	46.5
	18	21.0	0.32	0.9	0.9	0.4	2.8	43.1	44.4
	Average	21.0	0.33	0.9	0.8	0.4	2.6	40.3	41.7
60	3	37.8	0.25	0.7	0.6	0.3	3.7	50.3	53.5
	15	41.2	0.22	0.7	0.7	0.3	3.7	55.5	57.5
	17	40.2	0.24	0.8	0.7	0.4	3.7	60.3	61.3
	Average	39.7	0.24	0.7	0.7	0.3	3.7	55.4	57.4
80	6	48.2	0.21	0.7	0.6	0.5	3.7	52.2	57.5
	11	55.6	0.21	0.6	0.6	0.4	3.4	59.2	62.2
	14	51.6	0.23	0.7	0.6	0.4	4.1	62.9	68.2
	Average	51.8	0.22	0.7	0.6	0.4	3.7	58.1	62.6
100	1	59.2	0.22	0.7	0.6	0.4	3.5	55.2	58.0
	9	51.8	0.20	0.7	0.6	0.4	4.0	58.1	63.5
	13	62.5	0.20	0.7	0.7	0.4	3.6	61.7	71.6
	Average	57.8	0.21	0.7	0.6	0.4	3.7	58.3	64.4
120	2	73.5	0.18	0.7	0.6	0.3	4.4	68.2	70.6
	5	59.8	0.19	0.6	0.6	0.4	4.1	56.4	58.6
	12	79.1	0.19	0.7	0.6	0.3	3.9	73.4	77.4
	Average	70.8	0.19	0.7	0.6	0.3	4.1	66.0	68.9
150	4	78.2	0.15	0.5	0.5	0.2	4.4	61.8	63.8
	8	79.9	0.15	0.6	0.5	0.3	4.5	65.9	71.8
	10	68.5	0.17	0.7	0.5	0.3	4.3	65.6	68.0
	Average	75.5	0.16	0.6	0.5	0.3	4.4	64.4	67.9
				1973–1982 period					
30	7	29.6	0.28	0.6	0.6	0.3	2.1	35.9	34.3
	16	30.2	0.30	0.8	0.8	0.2	2.0	42.4	40.7
	18	30.6	0.28	0.5	0.7	0.2	1.9	35.1	33.8
	Average	30.1	0.29	0.6	0.7	0.2	2.0	37.8	36.3
60	3	55.3	0.21	0.7	0.5	0.1	3.0	56.9	54.5
	15	57.9	0.21	0.6	0.5	0.1	3.0	55.1	52.8
	17	59.0	0.19	0.6	0.6	0.1	2.6	53.9	52.1
	Average	57.4	0.20	0.6	0.5	0.1	2.9	55.3	53.1
80	6	70.4	0.15	0.8	0.6	0.0	3.0	60.6	58.0
	11	76.2	0.15	0.4	0.4	0.0	2.4	49.9	48.4
	14	74.1	0.17	0.7	0.4	0.1	3.2	64.1	61.8
	Average	73.6	0.16	0.6	0.5	0.0	2.9	58.2	56.1
100	1	89.9	0.13	0.6	0.3	0.0	3.2	61.5	59.0
	9	82.8	0.13	0.6	0.5	0.1	3.5	66.1	64.5
	13	86.0	0.13	0.8	0.5	0.0	3.1	71.5	69.2
	Average	86.2	0.13	0.7	0.4	0.0	3.3	66.4	64.2
120	2	105.5	0.12	0.5	0.2	0.1	3.3	62.6	60.0
	5	95.6	0.12	0.4	0.4	0.1	3.5	60.4	61.3
	12	109.3	0.12	0.6	0.4	0.0	2.9	68.9	67.4
	Average	103.5	0.12	0.5	0.3	0.1	3.2	64.0	62.9
150	4	115.5	0.10	0.5	0.3	0.1	3.7	67.7	67.1
	8	114.3	0.10	0.5	0.3	0.0	3.9	74.8	76.3
	10	107.0	0.11	0.8	0.3	0.0	4.0	86.3	84.6
	Average	112.3	0.10	0.6	0.3	0.0	3.9	76.3	76.0

the second period (table 3). The change in crown length was negatively correlated with residual basal area during both periods. Coefficients of determination for equations predicting mean annual change in crown length as a function of residual basal area were 0.500 and 0.764 for the two periods, respectively. During the second growth period of 1973–82, and after the 1963–72 period of adjustment, changes in crown length were more highly correlated with stand density. This contrasts with results for height growth. The significance level for the test of identical equations was 0.13; therefore, the equations were assumed to be the same. The equation resulting from the merged data set for the two growth periods is:

$$CLG = 0.87789 - 0.00509\ BA$$
$$R^2 = 0.738$$
$$S_{y \cdot x} = 0.084$$

where: CLG = periodic annual crown length growth (ft).

The negative effect of increasing stand density on crown length growth resulted in live crown ratios also showing a negative relationship to increasing GSL (table 2). Average live crown ratio for each GSL treatment ranged from 49% to 45% after the initial thinning, and had increased to 68–53% with increasing GSL after the third thinning in 1982. The pronounced differences in live crown ratio can be expected to continue as the higher GSL plots continue to increase in residual basal area.

Crown Width Growth

Periodic annual crown width growth of measured trees (fig. 7) ranged from 0.5 to 0.2 foot (0.15 to 0.06 m), decreasing with increasing basal area during the first period, and from 0.3 foot (0.09 m) to no change during the second period (table 3). Changes in crown width were negatively correlated with residual basal area during both periods; but the relationships were not as strong as those for crown length growth. Coefficients of

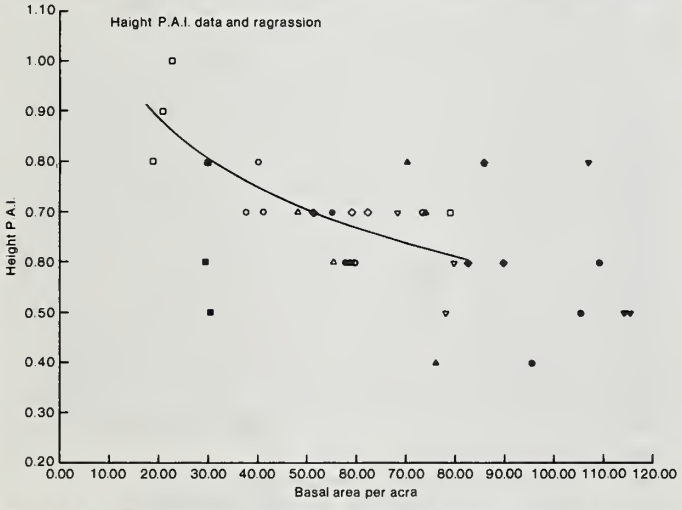

Figure 5.—Relationship of periodic annual height growth to residual basal area for the 1963-72 period.

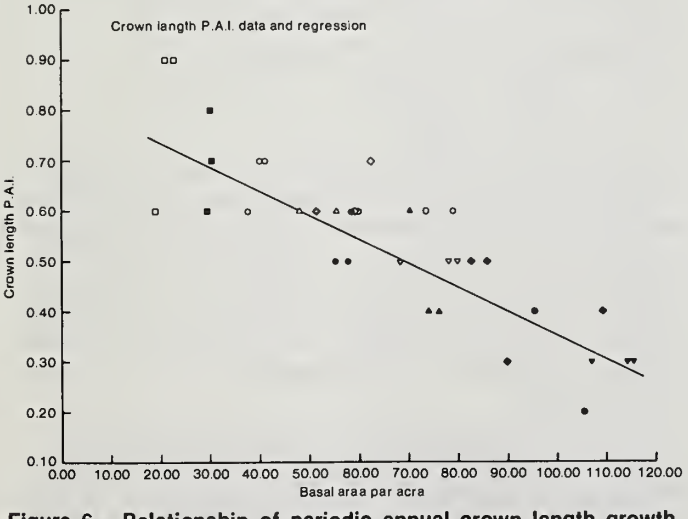

Figure 6.—Relationship of periodic annual crown length growth to residual basal area for the combined periods (1963-82).

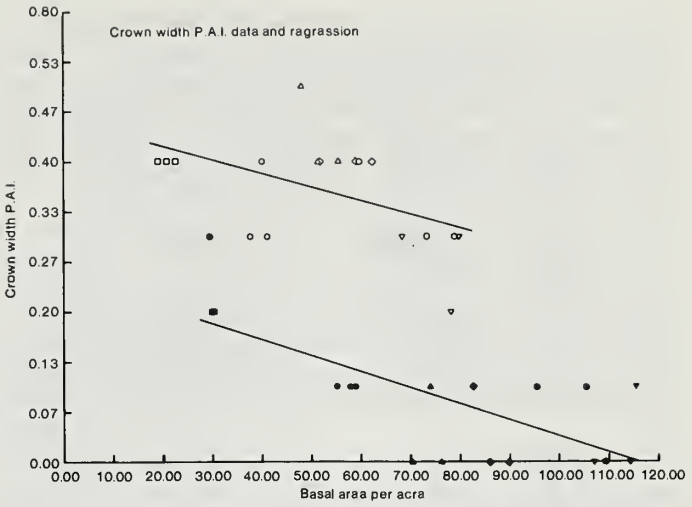

Figure 7.—Relationship of periodic annual crown width growth to residual basal area for the 1963-72 and 1973-82 periods.

determination for equations predicting mean annual crown width growth as a function of residual basal area were 0.261 and 0.518 for the 1963–72 and 1973–82 periods, respectively. As with crown length, the relationship was stronger during the second growth period. Because the significance level for the test of identical equations was nearly zero, the equations were assumed to be different in figure 7. The equation for the 1963–72 period is:

$$CWG = 0.45714 - 0.00182\ BA$$
$$S_{y \cdot x} = 0.062$$

where: CWG = periodic annual crown width growth (ft).

The corresponding equation for the 1973–82 period is:

$$CWG = 0.24889 - 0.00215\ BA$$
$$S_{y \cdot x} = 0.061.$$

The significance level for the test of equal slope coefficients was 0.72, which indicates that only the intercepts were different. The largest change in crown width was expected to occur during the adjustment period after the initial thinning, with reduced changes thereafter. Results from the second growth period suggest little or no crown width development can be expected at higher stand densities. A decreasing linear trend of crown width growth with residual stand density also was noted by Oliver (1979).

Basal Area Increment

Periodic annual basal area increment (fig. 8) ranged from 2.2 to 4.5 square feet per acre (0.51 to 1.03 m^2/ha), increasing with basal area during the 1963–72 period, and from 1.9 to 4.0 square feet per acre (0.44 to 0.92 m^2/ha) during the 1973–82 period (table 3). Basal area increment was positively correlated with residual basal area during both periods. Coefficients of determination for equations predicting mean annual basal area increment as a function of the logarithm of

residual basal area were 0.788 and 0.750 for the two periods, respectively. Because the significance level for the test of identical equations was nearly zero, the equations were assumed to be different. Basal area increment was consistently greater during the initial adjustment period, then slowed during the second growth period. The equation for the 1963–72 period is:

$$BAI = -1.00087 + 1.21352 \ln BA$$
$$S_{y \cdot x} = 0.292$$

where: BAI = periodic annual basal area increment (square feet per acre).

The corresponding equation for the 1973–82 period is:

$$BAI = -2.00117 + 1.17756 \ln BA$$
$$S_{y \cdot x} = 0.319.$$

The significance level for test of equal slope coefficients was 0.88, indicating the equations differed only in intercept values. As noted earlier, this decrease in growth rate over time is expected. Basal area growth values for the first 10-year period are slightly higher than for the 5-year period immediately after initial thinning (Schubert 1971). As with diameter growth, this difference was because of the response delay during the 5-year period after initial thinning.

Barrett (1983) and Oliver (1979) obtained similar significant, positive curvilinear relations to residual GSL. Basal area growth across GSLs in the central Oregon study varied greatly and averaged slightly less than at Taylor Woods. Annual basal area growth values from the high site quality, northern California study ranged from 4.7 to 9.0 square feet per acre (1.08 to 2.07 m²/ha),roughly twice the rate observed at Taylor Woods.

Total Cubic Volume Increment

Periodic annual total volume increment (fig. 9) ranged from 31.0 to 74.8 cubic feet per acre (2.17 to

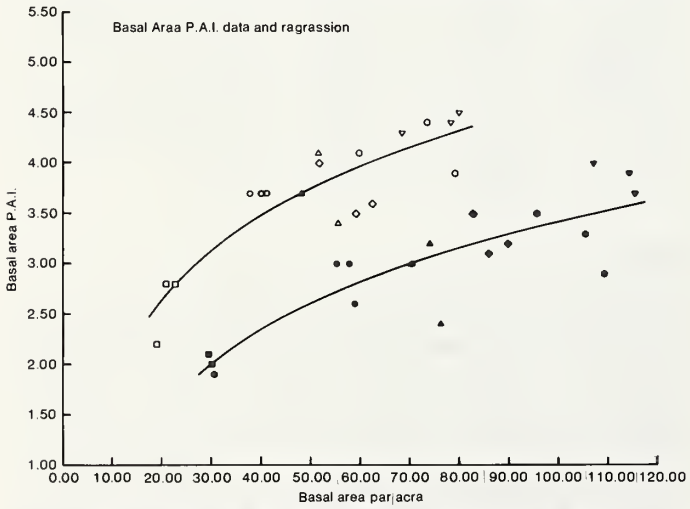

Figure 8.—Relationship of periodic annual basal area increment to residual basal area for the 1963–72 and 1973–82 periods.

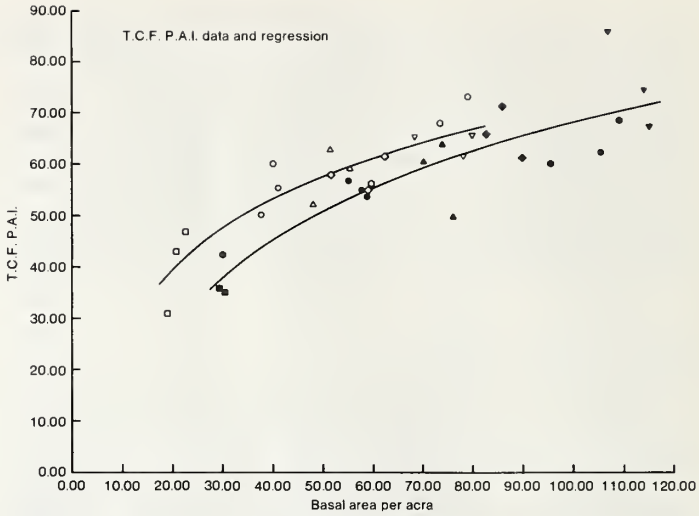

Figure 9.—Relationship of periodic annual total volume increment to residual basal area for the 1963–72 and 1973–82 periods.

5.24 m³/ha), increasing with basal area during the 1963–72 period, and from 35.1 to 86.3 cubic feet per acre (2.46 to 6.04 m³/ha) during the 1973–82 period (table 3). As with basal area increment, total volume increment was positively correlated with residual basal area during both periods. Coefficients of determination for equations predicting mean annual total volume increment as a function of the logarithm of residual basal area were 0.809 and 0.776 for the two periods, respectively. The significance level for the test of identical equations was 0.01, and the equations again were assumed to be different. The curve derived from the first period equation lies above that drawn from the second period equation over the range of data for each period. However, the curves converge at high basal areas, instead of diverging slightly compared to those based on equations for basal area increment. The equation for the 1963–72 period is:

$$TVI = -20.24236 + 19.91733 \ln BA$$
$$S_{y \cdot x} = 4.487$$

where: TVI = periodic annual total volume increment (cubic feet per acre).

The equation for the 1973–82 period is:

$$TVI = -48.42243 + 25.36184 \ln BA$$
$$S_{y \cdot x} = 6.404.$$

The significance level for the test of equal slope coefficients was 0.20, which indicates most of the difference between the equations is because of the intercept terms. As expected, there is a decrease in the growth relationship over time, even though annual volume production at higher densities is greater for the second growth period than the first. This is because of higher residual basal areas at the beginning of the second 10-year period.

During the first 5-year period after the initial thinning, annual volume growth leveled off at slightly more than 50 cubic feet per acre (3.50 m³/ha) from GSLs of 80 to 150 with residual basal areas of 37.8 to 66.2 square feet per acre (8.68 to 15.20 m²/ha) (Schubert 1971). Con-

trary to these earlier findings, results from two 10-year growth periods show volume growth does not level off, but generally increases for residual basal areas of at least 115 square feet per acre (26.40 m²/ha). Barrett (1983) and Oliver (1979) also found this increase for residual basal areas of at least 150 square feet per acre (34.44 m²/ha) on higher site quality lands. At higher stand densities in the central Oregon study, there was a suggestion of leveling off in volume growth during the period after the second thinning (Barrett 1983). This pattern at high stand densities has not been observed at Taylor Woods, however.

Merchantable Cubic Volume Increment

Periodic annual merchantable volume increment (fig. 10) ranged from 34.2 to 77.4 cubic feet per acre (2.39 to 5.42 m³/ha), increasing with basal area during the 1963–72 period, and from 33.8 to 84.6 cubic feet per acre (2.37 to 5.92 m³/ha) during the 1973–82 period (table 3). Merchantable volume increment was larger than total volume increment on most plots during the first period; but this occurred on only two plots at higher residual densities during the second period. Differences were a result of ingrowth of trees over the 5-inch (12.7-cm) d.b.h. limit. Merchantable volume increment also was positively correlated with residual basal area during both periods. Coefficients of determination for equations predicting mean annual merchantable volume increment as a function of the logarithm of residual basal area were 0.832 and 0.787 for the 1963–72 and 1973–82 periods, respectively. The significance level for the test of identical equations was nearly zero; and the equations were assumed to be different at a high level of significance, partly because of ingrowth during the first period. The equation for the 1963–72 period is:

$$MVI = -24.87408 + 21.98153 \ln BA$$
$$S_{y \cdot x} = 4.583$$

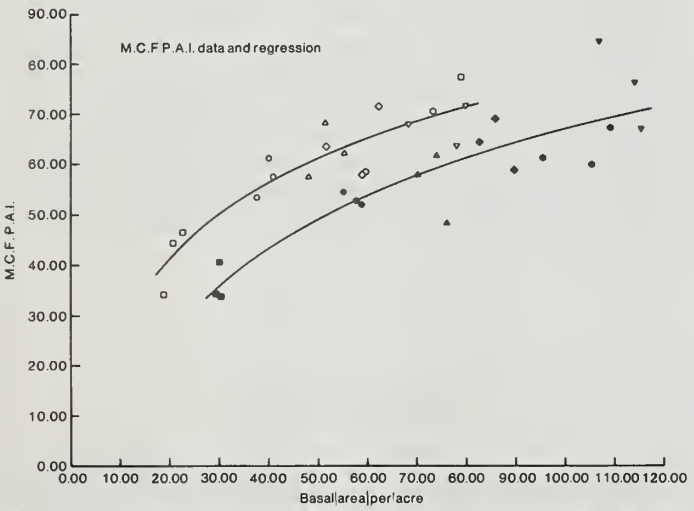

Figure 10.—Relationship of periodic annual merchantable volume increment to residual basal area for the 1963-72 and 1973-82 periods.

where: MVI = periodic annual merchantable volume increment (cubic feet per acre).

The equation for the 1973–82 period is:

$$MVI = -52.58725 + 25.97547 \ln BA$$
$$S_{y \cdot x} = 6.340.$$

The significance level for the test of equal slope coefficients was 0.35, indicating the main difference in equations is due to the intercepts. As with annual total volume growth, this decrease is expected. Also, at high stand densities in the second growth period, annual merchantable volume growth exceeded growth during the first period, again because of higher residual basal areas.

Results from the first 5-year period after the initial thinning indicated a leveling off in merchantable volume production at GSL 80; but the growth at higher GSLs varied greatly (Schubert 1971). This variability mainly resulted from varying ingrowth into the merchantable size classes. As with total volume production during the two 10-year growth periods, merchantable volume growth generally increased with higher residual stand densities. Contrary to the results of the first 5-year growth period, this result indicates that significant volume production is sacrificed at lower stand densities.

Ingrowth over the 7 inch (17.8 cm) minimum d.b.h. for calculation of board foot volume varied greatly during both growth periods, especially at the higher residual densities. It was not possible, therefore, to develop a meaningful relationship between board foot volume growth to residual density for the first 20 years after initial thinning. However, trees should reach adequate size during the next growth period, allowing board foot volume to be analyzed across all stand densities.

Merchantable Volume Removals

Merchantable cubic-foot volumes removed per acre during the 1972 and 1982 thinnings are shown in figure 11. Depending on the minimum volume per acre that would be considered economically feasible, commercial yields were produced at all GSLs in 1982, except possibly the highest; whereas in 1972, merchantable volumes were harvested only from the lowest GSLs. Although the results may be somewhat misleading because of the short 10-year cutting cycle, they indicate that managing stands with small average diameters at high GSLs may be a problem if only one precommercial thinning is allowed (Alexander and Edminster 1980).

Although there was considerable variability in yields from plots at each GSL, it was still possible to develop a relationship for each thinning. The equations that follow are also plotted in figure 11.

The equation for the 1972 thinning is:

$$MCR = 227.59106 - 1.57225 GSL$$
$$R^2 = 0.734$$
$$S_{y \cdot x} = 39.335$$

where: MCR = merchantable volume removed (cubic feet per acre).

The corresponding equation for the 1982 thinning is:

$$MCR = 375.88671 - 1.30942\ GSL$$
$$R^2 = 0.589$$
$$S_{y \cdot x} = 45.461.$$

The test for identical equations had a significance level of nearly zero, indicating that the equations were different. The increased variability surrounding the 1982 equation was caused by somewhat lower yields from the GSL 30 plots in relation to the other plots and highly variable yields at the higher GSLs. The significance level for the test of equal slope coefficients was 0.48, indicating the difference in the equations results from the intercepts. The increased yields from the 1982 thinning are the result of larger trees being removed than in 1972. The decreasing trend of merchantable volume removed with increasing GSL at each thinning results from smaller trees being cut at the higher GSLs and more trees being retained as growing stock. In the 1972 thinning, few trees that were cut at the higher GSLs met the minimum merchantability limit. The number of trees per acre removed in 1972 varied extremely and was not related to GSL. The number of trees removed during the 1982 thinning generally increased with increasing GSL.

Conclusions

The growth relationships between tree and stand characteristics and stand density determined in this study were similar to those found by Oliver (1979) and Barrett (1983). With the exception of height growth, all averages of other tree characteristics examined in this study showed a negative growth relationship with increasing stand density. The two- to three-fold increase in periodic annual diameter growth and the two-thirds increase in average diameter between the highest and lowest density levels confirm early observations of the potential of southwestern forests. These increases also demonstrate the ability of ponderosa pine to respond to thinning. Stand characteristics such as basal area and volume increment, in contrast, showed a positive relation to increasing stand density. Volume production declined substantially when GSL was reduced below 150, and the decline was greater with successive reductions in stand density.

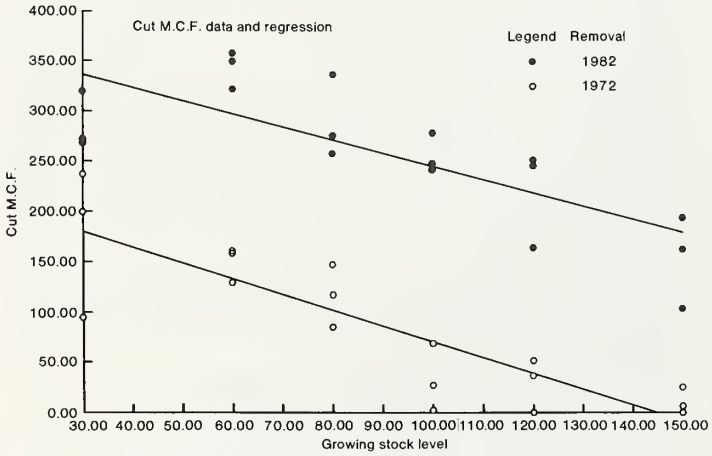

Figure 11.—Relationship of merchantable cubic volume removed in 1972 and 1982 to the specified growing stock level goal.

Tree damage and mortality have had little effect on the results of the first 20 years. With the exception of damage caused by heavy, wet snows in the spring of 1963 (Schubert 1971), mortality for all GSLs has been negligible for subsequent growth periods (table 2). Similarly, overall mortality in the California plantation was not important (Oliver 1979).

Barrett (1983), however, noted that considerable mortality occurred in the Oregon study, all associated with attacks by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.), and mostly at the higher stand density levels (GSLs 120 and 150). In the Taylor Woods study, plots at GSL 150 have not reached residual basal areas which are subject to infestation by the mountain pine beetle. These plots, however, will exceed the apparent critical stand density of 150 square feet of basal area per acre (34.44 m^2/ha) when average diameter reaches 10 inches (25.4 cm) (Sartwell and Stevens 1975).

Drawing conclusions about long-term yields from this study may be premature, considering differences in volume production observed between the first 5-year (Schubert 1971) and the 20-year periods after initial thinning; but, certain conclusions concerning intermediate management of even-aged stands can be reached. These depend on the number of precommercial thinnings which may be performed, and whether a market exists for roundwood or only for sawtimber. Current stand management practices generally allow for no more than one precommercial thinning. Examination of table 2 shows that relatively small amounts of basal area were removed in the 1972 thinning on plots with a GSL of 100 or more. Also, only two plots at GSL 30 yielded more than 2 cords per acre (approximately 180 cubic feet per acre or 12.60 cubic meters per hectare) of roundwood in trees 5 inches (12.7 cm) d.b.h. and larger in 1972. By 1982, only one plot at GSL 30 yielded more than 1,000 fbm per acre (14.0 m^3/ha) in trees 7 inches (17.8 cm) d.b.h. and larger. These results suggest cutting cycles of about 20 years for roundwood and a minimum of about 30 years for sawtimber with a minimum diameter limit of 7 inches (17.8 cm).

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A dense, immature ponderosa pine stand was thinned in 1962, 1972, and 1982 to six growing stock levels. Except for height, average tree growth characteristics (diameter, crown length, and width) were negatively correlated with residual stand density. Stand basal area and volume increment were positively related to stand density.

Keywords: Silviculture, mensuration, growing stock, stand density, stand growth, thinning, *Pinus ponderosa*

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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